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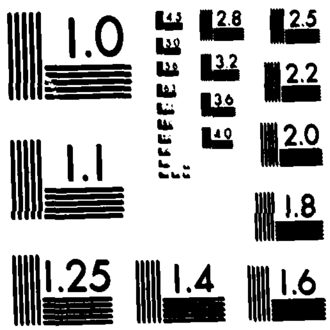

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THE DEVELOPMENT OF TYPEWRITING SKILL

Donald R. Gentner

CENTER FOR HUMAN INFORMATION PROCESSING

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The Development of Typewriting Skill

Donald R. Gentner

Center for Human Information Processing

University of California, San Diego

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Center for Human Information Processing

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ABSTRACT

Typewriting, like handwriting, is an example of a highly practiced motor skill. Professional typists spend about a year learning to type and accumulate thousands of hours of practice during their working lives. I studied 18 typists, ranging from beginning students in a typing class (about 1 keystroke/second) to expert professional typists (about 10 keystrokes/second).

All typists became faster with practice, but the rate and amount of improvement varied for different classes of keystroke sequences, and the pattern of keystroke times displayed qualitative changes with the development of typewriting skill. For example, double letters, such as <u>dd</u>, were the fastest keystroke sequences for student typists, but they were among the slowest sequences for professional typists. In addition, the relative variability of the interstroke intervals decreased with learning. The most striking changes were for one-finger non-doubles, such as <u>de</u>, which were the most variable intervals for beginners and the least variable intervals for experts. Finally, the correlation between successive interstroke intervals for some letter sequences became more negative with learning.

These experimental findings are interpreted in terms to two general developmental changes: (1) the finger movements become less sequential and more overlapping with practice; (2) performance shifts from being limited by cognitive constraints in students to being limited by motoric and physical constraints in experts.

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The research reported here was conducted under Contract N00014-79-C-0323, NR 667-437 with the Personnel and Training Research Programs of the Office of Naval Research, and was sponsored by the Office of Naval Research and the Air Force Office of Scientific Research. I am especially grateful for numerous conversations with other members of the CSL research group including Jonathan Grudin, Serge Larochelle, Donald Norman, and David Rumelhart. Eileen Conway and Patty Haden assisted in many phases of these studies.

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Introduction

Handwriting and typewriting present a set of similarities and contrasts. Both skills are used to produce written language and are learned and practiced over periods of many months and years. Handwriting and typewriting are thus quite different from the motor skills commonly studied in the psychological laboratory, in which the subject learns and practices an arbitrary movement for a few hours at most.

One of the most important contrasts between typewriting and handwriting is that typing is composed of discrete events when analyzed at the level of the keystroke, whereas handwriting is a continuous action. It is therefore much simpler to define correct performance and event times in typing. A letter either appears on the typewritten page or it does not. The letter has a well defined place and serial order, and the keystroke, especially with an electronic keyboard, has a discrete and easily measured time. In contrast, handwritten letters can be more or less well formed, can be made in any size and position, and are drawn over a period of time. Perhaps this contrast is a little misleading, because when analyzed, for example, at the level of finger movements, typing is just as continuous as handwriting. Nonetheless, the discrete nature of the keystroke affords a greatly simplified description of typewriting, and is probably the reason that almost all studies of typing are based on analyses at the keystroke level. (For studies of typing at the level of finger movements, see Gentner, Grudin & Conway, 1980 and Gentner, 1982.)

Another contrast between typewriting and handwriting is that transcription typing is typically learned in early adulthood, when the motor system is fully developed and stable. Because handwriting is normally learned by young children, the development of handwriting skill is confounded with the general maturation of the motor system. Also, from the practical standpoint of studying the development of a motor skill, the fact that not everyone learns to type means that it is possible to find people of the same age and general ability, but with typing skills ranging from the complete novice to the expert.

Over the past few years, in collaboration with Jonathan Grudin, David Rumelhart, Donald Norman, and Serge Larochelle, I have been studying transcription typing in the laboratory. Typically, typists would be asked to transcribe normal English prose from typewritten copy. This corpus of naturalistic data, now totaling over half a million keystrokes, has been a rich vein of information on the development and performance of a highly practiced motor skill.

Method

Typists

This paper is based on data collected from ten professional typists (Typists 1-10) who were normally employed as secretaries in the university or local businesses. I refer to this group as the "expert typists." Their typing speeds on the experimental text ranged from 61 to 112 words per minute (wpm), assuming five keystrokes per word and with no adjustment for errors. A second group of eight typists (Typists 21-28), the "student typists," were students in a beginning typing class from a local high school. The student typists were studied once a week in the third through eighth week of their typing class. The students did not type all the letters of the alphabet until the fourth week, so data from the third week were not included in these analyses. Their typing speeds on the experimental texts ranged from 13 wpm for one student in the fourth week to 41 wpm for another student in the eighth week. The data from the student typists were collected by Jonathan Grudin and kindly furnished by him.

Texts

The text typed by the expert typists was adapted from a _Reader's Digest_ article on diets; it will be referred to as the "diet text." The diet text was approximately 12,000 characters long and was presented as double-spaced, typewritten copy. After a 10 minute warmup with another text, the typists were asked to transcribe the diet text at their normal, rapid rate, without correcting errors. The student typists were given a variety of texts to transcribe. The texts for the fourth and fifth weeks consisted of a number of unrelated prose paragraphs. The remaining texts for the student typists were prose passages adapted from _Reader's Digest_ articles.

Apparatus

The typists worked at a high-quality electronic keyboard (Microswitch model 51SD12-4 with "tactile feel"). The keyboard layout was identical to that of the normal IBM Selectric typewriter (see Figure 1). Keypresses and the corresponding times, with a resolution of 1 msec, were recorded by a microcomputer. As characters were typed, they were displayed on a CRT in front of the typist.

Results

I found three major developmental trends in typewriting. First, typing became faster with practice, but the increase in speed varied for different classes of keystroke sequences. Second, the correlation between successive interstroke intervals of some letter sequences became more negative for the more expert typists. Third, the variability in timing of repeated sequences decreased, but again the amount of decrease varied for different keystroke sequences. These trends were evident both in the longitudinal development of an individual and in comparisons

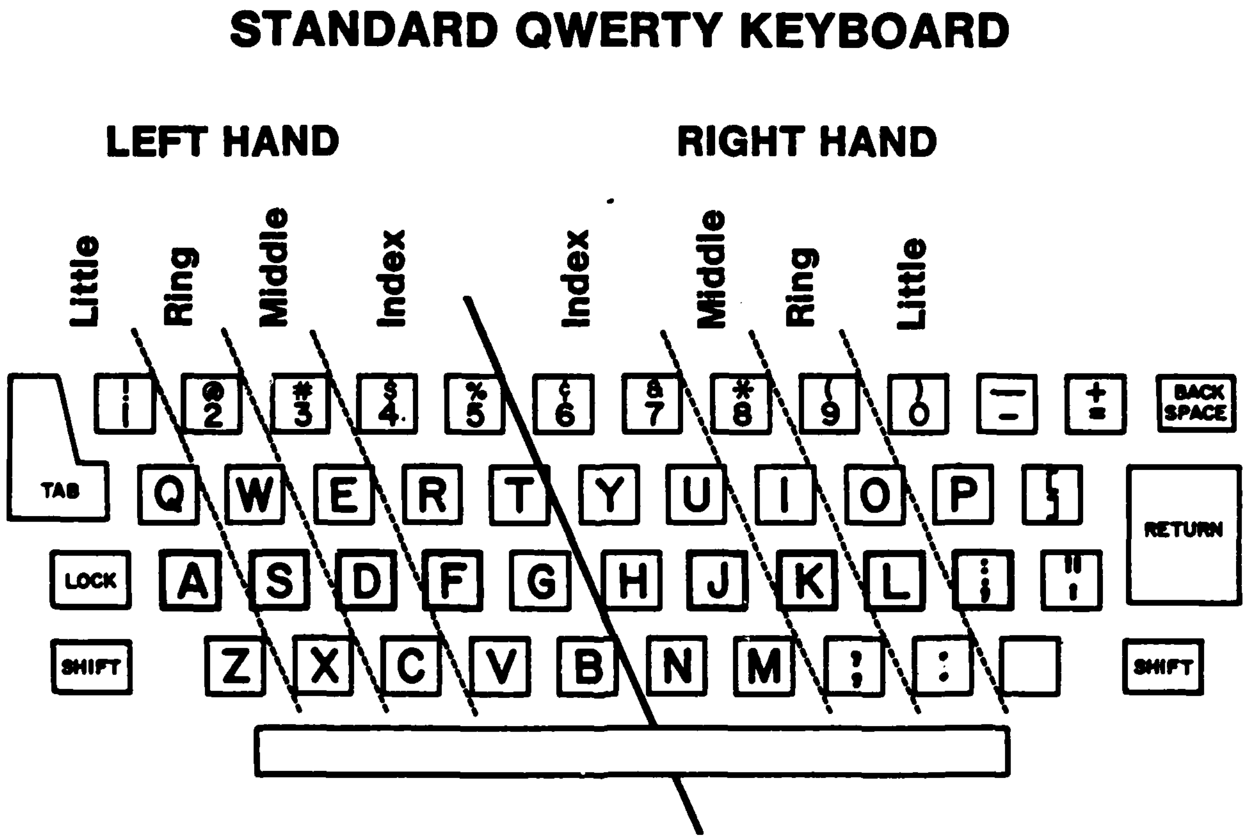

Figure 1. The layout of the keyboard used in these studies. This is the standard American "qwerty" keyboard and is identical to the layout of the IBM Selectric typewriter.

across typists of differing skill levels.

Changes in Speed

The most prominent developmental change in typists is well known: typists get faster with practice. Figure 2 illustrates this progression by showing the interstroke interval distributions for a student typist at four and eight weeks, a typical office typist, and an unusually fast typist. The most obvious difference among these typists was a major increase in typing speed from 13 to 112 wpm and a corresponding decrease in the median interstroke interval from 852 to 96 msec.

The distribution of all interstroke intervals is actually a composite of different classes of intervals. Although there is a general increase in speed with practice, the amount of improvement varies depending on the class of interstroke interval. The interstroke intervals can be usefully grouped according to digraph classes. Sequences of two keys typed by a single finger are called one-finger digraphs (see the typewriter keyboard in Figure 1); the one-finger digraphs can be further subdivided into one-finger doubles, such as dd, and one-finger non-doubles, such as de. Sequences typed by two fingers on the same hand, such as se, are called two-finger digraphs. Sequences typed by different hands, such as pe, are called two-hand digraphs.

When the overall distributions of interstroke intervals were separated into the four digraph classes, a significant qualitative difference became apparent. The relative interstroke intervals of the four classes were different for beginning and expert typists. Figure 3 displays the median interstroke interval of the four digraph classes for all typists studied. Across the range of typists studied, the interstroke intervals for all digraph classes decrease. But whereas the median interstroke interval decreased by a factor of 12 for two-hand digraphs, it decreased by a factor of only 3 for one-finger doubles. With the slowest students, the interstroke intervals were similar for one-finger non-double, two-finger, and two-hand digraphs, but the interstroke intervals of one-finger doubles were only about half as long. The fastest typists showed quite a different pattern: one-finger digraphs, both double and non-double, were typed much more slowly than two-finger and two-hand digraphs. Figure 3 also shows a subtler progression for the two-finger and two-hand digraphs. In general, two-finger digraphs were slower than two-hand digraphs, but they tend to be similar for the slowest (below 25 wpm) and fastest (above 80 wpm) typists. For the middle range of typists, the median interstroke interval for two-finger digraphs is about 30% slower than for two-hand digraphs.

The patterns seen when contrasting student and expert typists also held when the progress of individual students was followed over several weeks. Newell and Rosenbloom (1981) found that, for a wide variety of tasks, a plot of the time to perform the task versus the number of trials produced a straight line in log-log coordinates. The slope of this line (with the sign changed) is the learning rate. Therefore, I

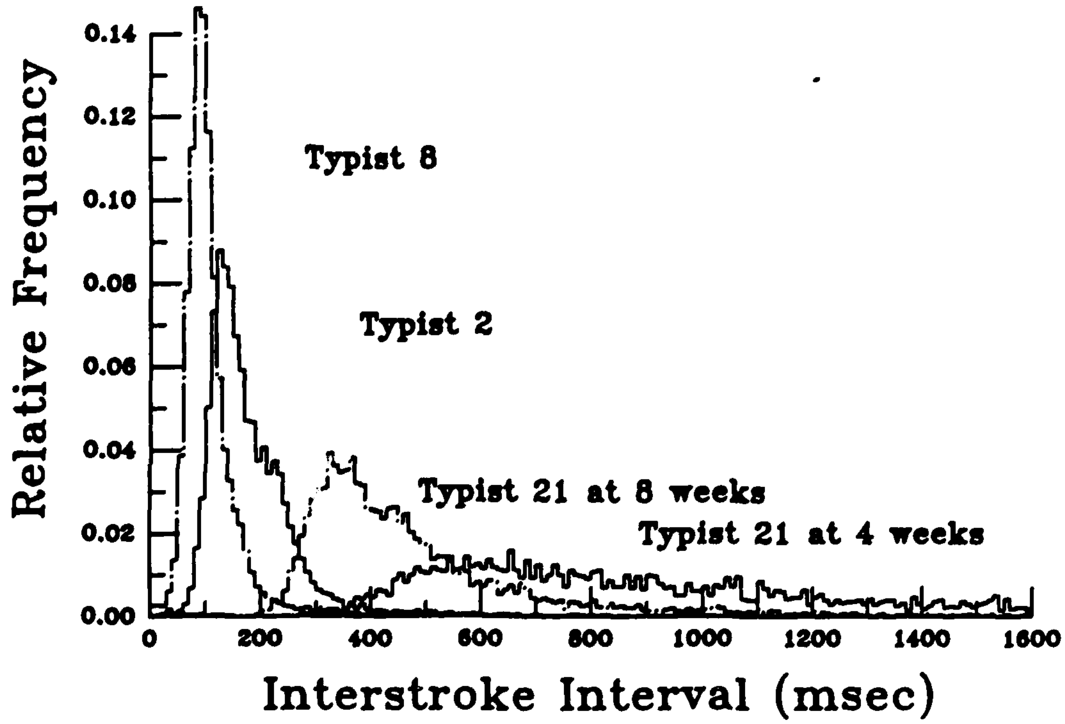

Figure 2. The distribution of all interstroke intervals for Typist 21 after 4 weeks (13 wpm) and 8 weeks (25 wpm) of typing class, Typist 2 (66 wpm) and Typist 8 (112 wpm).

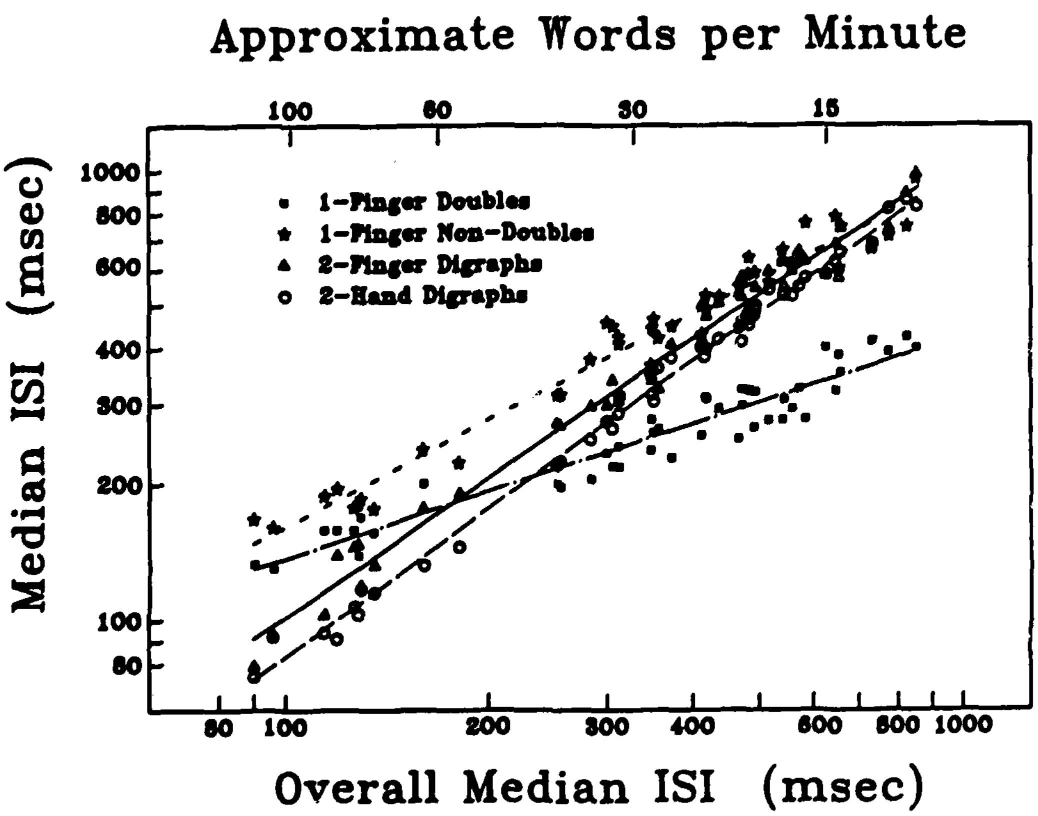

Figure 3. The median interstroke interval for one-finger double, one-finger non-double, two-finger, and two-hand digraphs plotted as a function of the typists' overall median interstroke interval. The fastest typist (112 wpm) is on the left; the slowest typist (13 wpm) is on the right. The data on the left are from 10 skilled typists; the data at center and right are from 37 sessions with 8 student typists in the fourth through eighth week of a beginning typing class. Note that one-finger doubles were among the slowest for skilled typists but fastest for the students.

calculated learning rates by plotting the median interstroke interval against the number of weeks in the typing course. While this is not quite legitimate, because the number of repetitions of a given digraph class varies from week to week, the procedure gives at least a reasonable estimate of the learning rate from these data. Typist 21 was the slowest typist initially and showed the greatest learning rate. Figure 4 shows the improvement of Typist 21 on the different digraph classes over the period of the study. Typist 21's learning rates for one-finger non-double, two-finger, and two-hand digraphs were more than twice that for one-finger double digraphs. (I should note that Typist 21's improvement could not continue at this rate indefinitely. If it did continue, Typist 21 would be typing at 113 wpm after 1 year and at 370 wpm after 4 years.) Table 1 lists the learning rates of all students for the four digraph classes. Although the other students had overall learning rates lower than Typist 21, their learning rates generally showed the same pattern with respect to digraph class as Typist 21. On average, compared with one-finger doubles, the learning rate was 176% higher for one-finger non-doubles, 273% higher for two-finger digraphs, and 210% higher for two-hand digraphs. The same developmental pattern was apparent when individual digraphs were examined, although these data were more variable because of the smaller number of observations.

Another study done in collaboration with David Rumelhart produced related results. In this study, expert typists were asked to transcribe a prose text both rapidly, as if it were a rough draft, and slowly, as if it were a final copy. One surprising result was that typing speeds only varied by about 20% between the two conditions, indicating that it is difficult for typists to make large changes in their overall typing speeds. However, when the interstroke intervals were separated into the four digraph classes, a pattern emerged very similar to the developmental pattern described above. As shown in Table 2, one-finger doubles changed the least between the rapid and slow conditions, and two-finger and two-hand digraphs changed the most.

Changes in Sequential Performance

Motor skills are typically composed of a series of coordinated movements. A central task for typists is to control their finger movements in time, so that the keys are struck in the proper serial order. Several models of typing have been proposed to describe the sequencing and timing of the keystrokes (Lashley, 1951; Shaffer, 1978; Sternberg, Monsell, Knoll & Wright, 1978; Terzuolo & Viviani, 1980). One basic distinction is between serial models of timing, in which the time of each event is based on the previous event, and parallel models of timing, in which several events are performed as a unit. Wing (1973) attempted to distinguish between serial and parallel models of timing in a finger tapping task by measuring the correlation between successive time intervals. Simple models of timing predict a negative correlation between successive interstroke intervals for parallel timing and no correlation for serial timing. The situation becomes more complicated when measurement errors and variations in the overall speed of performance are considered, and attempts to deduce underlying models of

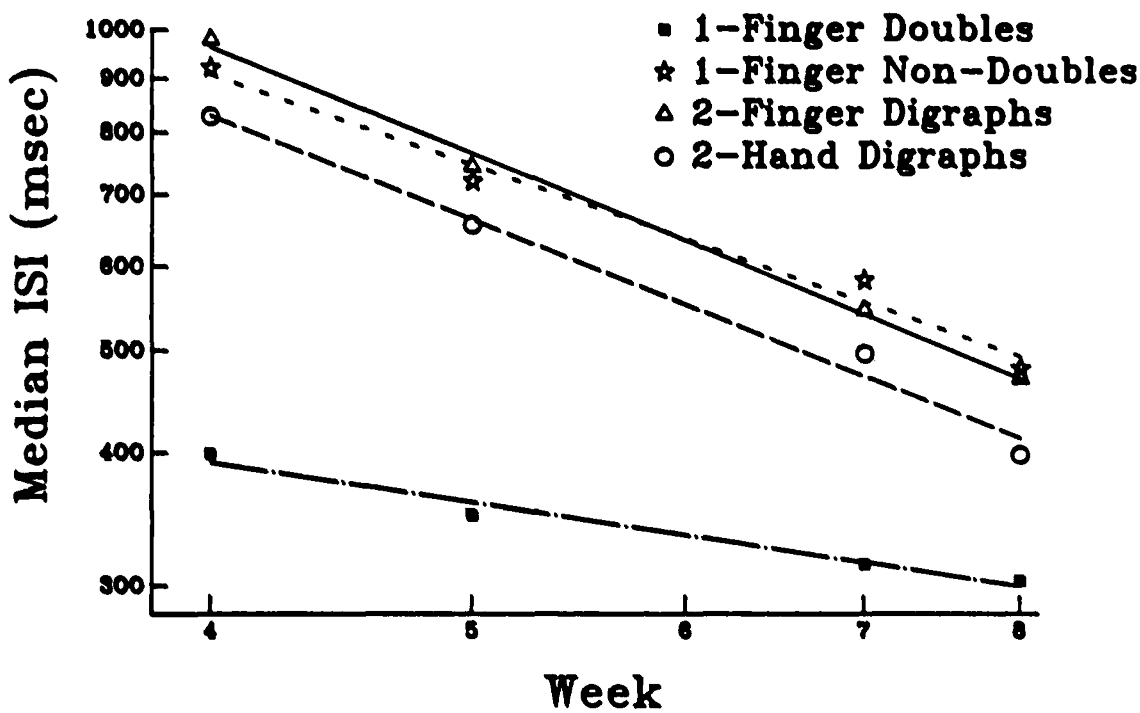

Figure 4. Learning curves for Typist 21 in the fourth through eighth week of a beginning typing class. The median interstroke interval (ISI) for each digraph class is plotted against the number of weeks in the typing course on a log-log scale. The learning rate for one-finger non-double, two-finger, and two-hand digraphs was about twice the learning rate for one-finger double digraphs.

Table 1

Learning Rates for Digraph Classes

Typist	1-finger Doubles	1-finger Non-Doubles	2-finger	2-hand	All Digraphs
21	.39	.88	1.03	1.01	1.00
22	.46	.20	.80	.35	.51
23	.10	.42	.64	.62	.61
24	-.12	.70	.52	.68	.63
25	.11	.52	.32	.28	.31
26	.11	.06	.32	.21	.25
27	.31	.39	.57	.58	.56
28	.05	.70	.92	.60	.71
Mean	.18	.48	.64	.54	.57

Table 2

% Increase in Median Interstroke Interval
for Digraph Classes

Typist	1-finger Doubles	1-finger Non-Doubles	2-finger	2-hand
2	1	5	23	29
3	6	7	12	11
4	9	9	13	20
Mean	5	7	16	20

timing from the times of observed events are fraught with difficulty. (For discussion of these issues, see Ohala, 1976 and Gentner, in press.) Nonetheless, it is generally true that more positive correlations between successive times indicate sequential events, and more negative correlations indicate parallel or overlapping events.

I calculated the correlation between successive interstroke intervals for several frequent letter sequences that occurred in all the texts typed by student and expert typists. In a number of cases, there was a general trend for the correlations to become more negative for the more skilled typists. I did not find any instances of letter sequences that became more positively correlated for the more skilled typists. However, there was a great deal of scatter in the data. Typists with similar typing rates had widely differing correlations, and some letter sequences showed no developmental trend. Figure 5 illustrates these results, showing the correlation between successive interstroke intervals in the common words the and and. These are both high-frequency words, with long alternating-hand sequences of right, left, right, left, right (the space bar is typed by the right thumb by almost all typists), so one would expect similar correlational results for the two words. Instead I found a decreasing correlation with increasing skill level for the, but no change in correlation with skill level for and. These results were typical of the sequences I examined. Most sequences showed no general developmental change in correlation, but a minority showed a general decrease in correlations with increasing typing speed.

Changes in Variability

Many typing teachers urge their students to type with a regular rhythm, and even use a metronome or march music to encourage students to develop regular time intervals between keystrokes. Nonetheless, it has been known for many years that the interstroke intervals of expert typists vary greatly depending on the sequence of letters being typed (Coover, 1923). This section examines the variability in interstroke intervals and how it changes as typing skill develops.

Figure 2 shows examples of the distribution of all interstroke intervals for several typists. The width of these distributions reflect the variability of the interstroke intervals for a given typist. This overall variability can be decomposed into two parts: a) variability caused by the different letter sequences being typed (task variability), and b) variability observed when the same letter sequence is repeatedly typed (repetition variability). This decomposition is illustrated in Figure 6, which contrasts the distribution of all intervals with the distributions of intervals embedded in specified contexts. The different medians of the two distributions (173 msec for the lo interval in alor versus 110 msec for the io interval in tion) represent task variability, and the half-widths of the distributions (29 msec for the lo interval and 11 msec for the lo interval) represent repetition variability.

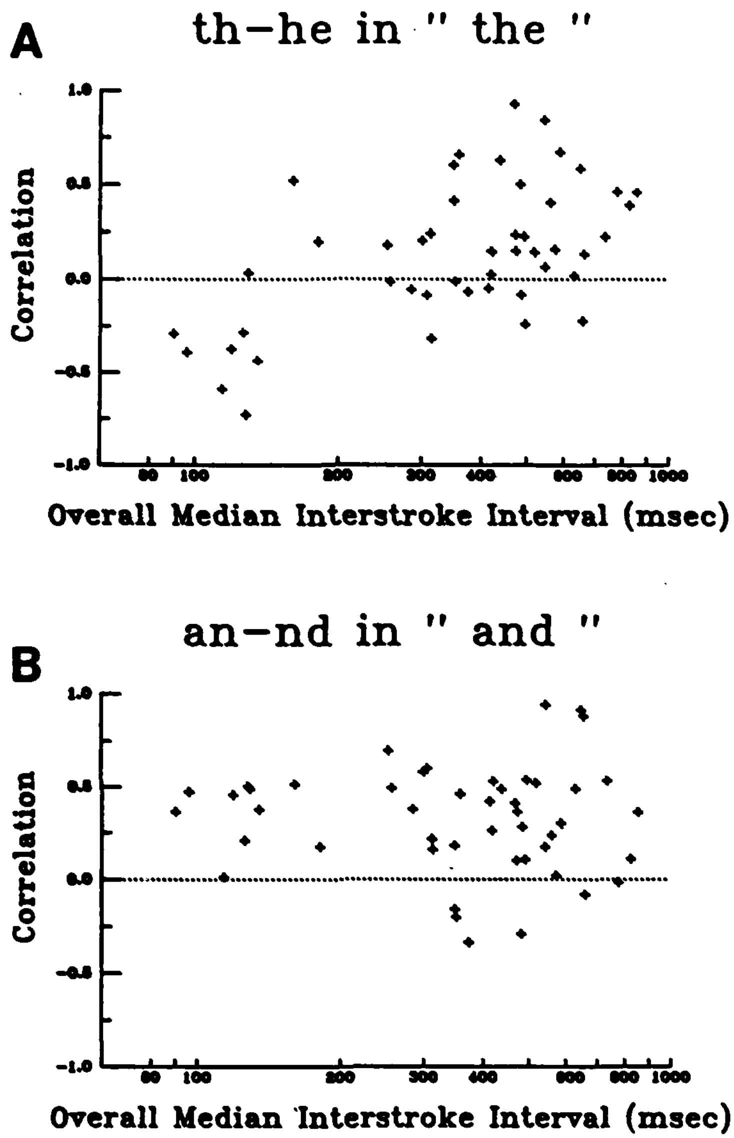

Figure 5. Panel A. Correlation between th and he interstroke intervals in the word the for typists at various skill levels. Panel B. Correlation between an and nd interstroke intervals in the word and for typists at various skill levels.

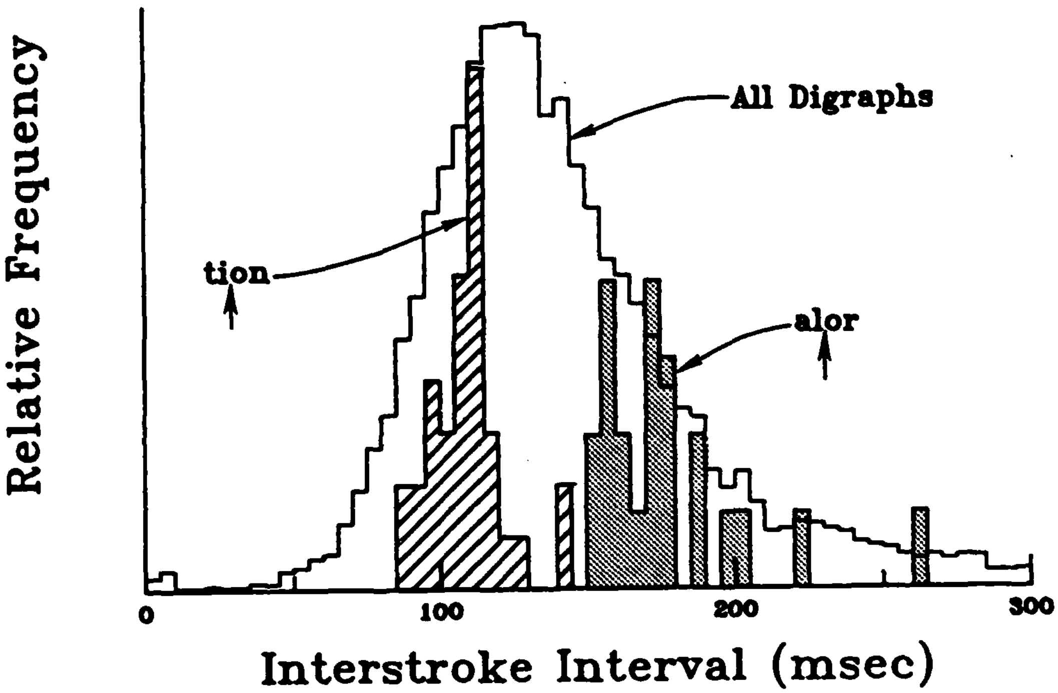

Figure 6. The distribution of all interstroke intervals is composed of many narrower distributions of interstroke intervals in specific contexts. This is illustrated with data from Typist 4 showing the distribution of all interstroke intervals, the distribution of lo intervals in the sequence alor, and the distribution of io intervals in the sequence tion. For Typist 4, the half-width of the overall distribution was 51 msec; the median half-width of distributions of intervals in four-character sequences was 19 msec.

<u>Task variability</u>. The portion of the variability caused by the different letter sequences typed is called the task variability. For expert typists, task variability is based primarily on the layout of the typewriter keyboard and the physical constraints of the hands and fingers (Rumelhart & Norman, 1982; Gentner, 1981).

A detailed analysis of the variability of interstroke intervals showed that the interstroke interval is influenced by the surrounding four-character context (Gentner, 1982). The bulk of the variance, however, is based on the two characters bounding the interval: the digraph. Thus, one rough measure of task variability is the degree to which median interstroke intervals differ for different digraph classes. This difference is shown graphically in Figure 3. If doubles are ignored, the amount of task variability increases with increasing typing skill. The median interstroke intervals for one-finger non-double, two-finger, and two-hand digraphs were essentially identical for the slowest students, but the medians for the three digraph classes were spread over a factor of two for expert typists. Inclusion of one-finger doubles complicates this analysis, because they were much faster than the other classes for students, but similar to one-finger non-doubles for experts. Thus, considering all four digraph classes, there was no overall developmental change in task variability, but there were qualitative changes in the source and nature of task variability.

<u>Repetition variability</u>. Even when a typist repeats exactly the same text, the corresponding interstroke intervals will vary from one typing to the next. I call this the repetition variability. Repetition variability is presumably based on fluctuations in such factors as level of attention, nerve conduction time, or arm position: any significant factor other than the text being typed.

As mentioned in the previous section, interstroke intervals were determined primarily by the surrounding four-character context. Thus, the half-width (the 3rd quartile minus the 1st quartile) of the distribution of interstroke intervals with a given four-character context is a good measure of the repetition variability. The different classes of digraphs characteristically differ in their repetition variability. It seems that the factors leading to repetition variability do not equally affect all digraph classes. Table 3 gives the median half-widths of distributions for intervals in three-character sequences for student and expert typists. (There were insufficient student data from four-character sequences for the comparison, but I would expect the results from three-character sequences to be very similar to the results from four-character sequences). The greatest developmental change occurs for one-finger non-doubles, which were twice as variable as other digraphs for students, but were extremely regular for experts.

Students, of course, have very long interstroke intervals and it is not surprising that their repetition variability is greater. But I found that one-finger non-doubles also became more regular in terms of the relative half-width (the half-width of the distribution divided by

Table 3

Repetition Variability
Medial Half-Width (msec) of the
bc Interval in the sequence abc

Typist	1-finger Doubles	1-finger Non-Doubles	2-finger	2-hand
Student	60	203	115	107
Expert	12	18	25	28

the median). Figure 7 shows the relative half-widths for all digraph classes. Note that the relative variability of one-finger non-doubles decreased dramatically going from students to experts. The relative variability of the other digraph classes is similar between experts and students, especially the faster students.

Discussion

Speed is one of the primary goals of typewriting. Because typists are normally trying to type as fast as they can, examination of the pattern of times that typists achieve can give insight into the constraints that form and limit their performance.

Earlier studies have shown that the interstroke intervals of expert typists were determined primarily by the layout of the keyboard and the physical constraints of the fingers and hands (Gentner, Grudin & Conway, 1980; Gentner, 1981; Rumelhart & Norman, 1982). One-finger digraphs were the slowest class of interstroke intervals for the experts, and for a given typist, the interstroke intervals were very similar for all one-finger digraphs. There were, however, small but systematic differences among the one-finger digraphs; the interstroke intervals were related to distance traveled on the keyboard. That is, doubles such as ee were fastest, digraphs one row apart such as de were intermediate, and digraphs two rows apart such as ce were slowest. Two-finger and two-hand digraphs, where it is possible to overlap the finger movements for successive keystrokes, were much faster than one-finger digraphs for experts. It was further found (Gentner, 1982) that there were large individual differences among experts in the interstroke intervals of two-finger digraphs. These differences were related to the amount of independent movement of fingers within a hand, again illustrating the central role of finger and hand constraints in determining interstroke intervals for expert typists.

The pattern of interstroke intervals found with student typists was very different. For beginning students, the interstroke intervals of one-finger non-double, two-finger, and two-hand digraphs were very similar and much slower than one-finger doubles. This suggests that student performance is limited by cognitive constraints rather than physical constraints. Doubles may be typed faster than non-doubles because the double is conceptualized as a two-letter unit, or because retrieval of the keyboard location is not necessary, given that the letter has just been typed. As student typists progress, their pattern of interstroke intervals changes smoothly into the expert pattern, mirroring a transition from cognitive limits (representation, memory retrieval, or serial processing) to motoric and physical limits (muscle strength, inability of overlap movements involving the same finger, or distance traveled).

These interpretations were supported by results from the computer simulation of a typist developed by Rumelhart and Norman (1982). Their typing simulation model does not have any central planning or control of timing. Instead, their simulation attempts to type several characters

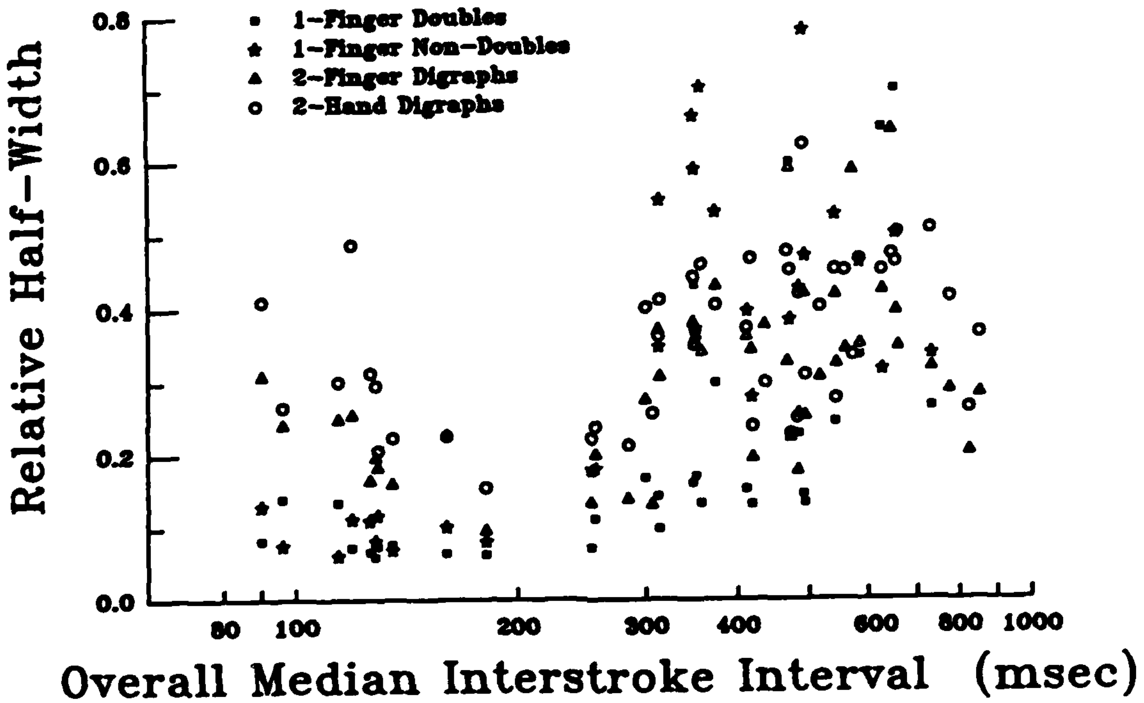

Figure 7. Repetition variability as a function of typing skill. Each set of four points on a vertical line represents data from one typist. Data for expert typists are shown on the left; data for student typists are on the right. The vertical axis represents the median relative half-width of the distribution of interstroke intervals in a fixed three-character context, for example, the <u>on</u> interstroke interval in the sequence <u>ion</u>. The relative half-width of a distribution is the difference of the third and first quartiles divided by the median.

at once, and the interstroke intervals are generated by competition among opposing goals to move the fingers to the different keyboard locations. In the model, the time between keystrokes is determined primarily by the keyboard layout and the constraints of the simulated hands. Because the model produces a pattern of interstroke intervals similar to those observed in expert typists, it is likely that similar constraints are determining the interstroke intervals of expert typists.

Producing a sequence of events in the proper serial ordered has always been a problem for theories of action. In the Rumelhart and Norman simulation model, the proper serial order is obtained by having each letter inhibit all following letters, thus making the first letter normally the most highly activated. Rumelhart (1982) found that, by decreasing the amount by which one letter inhibited following letters and thus increasing the degree to which several letters tend to be typed at once, the simulation model showed a pattern of changes similar to the pattern of developmental changes found in going from student to expert typists (see Figure 8). This simulation result suggests that an important component of the development of typewriting skill is the change toward a less sequential and more overlapped mode of performance.

I found that for some letter sequences, the correlation between successive interstroke intervals generally decreased with increasing typing skill. This finding also supports the view that typing becomes less sequential with increasing skill.

The developmental changes in variability roughly mirror the changes in interstroke intervals. Absolute and relative variability decreased with increasing skill. An analysis of task variability showed that student performance followed the natural cognitive division of digraphs into doubles and non-doubles. Task variability in expert performance, on the other hand, was based on the position of the keys and the finger and hand combinations used to type them. The analysis of repetition variability mirrored this difference. For students, the repetition variabilities of one-finger non-double, two finger, and two-hand digraphs were similar, and one-finger doubles were less variable. For experts, double letters loose the special characteristics they have with students, and behave like other one-finger digraphs.

These observations suggest a coherent picture of skill development consisting to two major factors. First, cognitive constraints form the major limitations on novice performance but motoric and physical constraints limit expert performance. Second, with increasing skill the keystrokes in typewriting become less sequential; aspects of performance overlap in time to exploit the degrees of freedom inherent in the task.

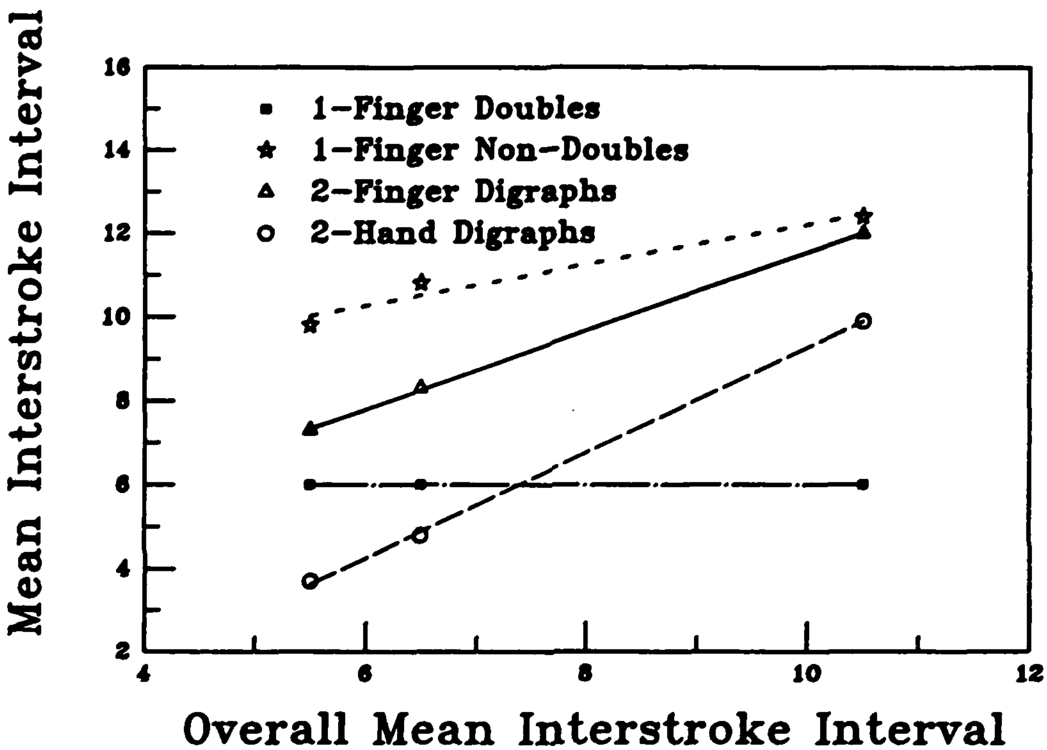

Figure 8. The effect of reducing the amount of inhibition between successive letters in the Rumelhart and Norman (1982) simulation model of a typist. Points on the right have the most inhibition; points on the left have the least inhibition. Decreasing the amount of inhibition decreases the average interstroke intervals and also changes the pattern interstroke intervals for the different digraph classes. Compare this figure with Figure 3.

References

Coover, J.E. A method of teaching typewriting based upon a psychological analysis of expert typing. National Education Association, 1923, 61, 561-567.

Gentner, D. R. Skilled finger movements in typing (Tech. Rep., CHIP 104). La Jolla, Calif.: University of California, San Diego, Center for Human Information Processing, 1981.

Gentner, D. R. Evidence against a central control model of timing in typing. Journal of Experimental Psychology: Human Perception and Performance, in press.

Gentner, D. R. Variability in skilled movement. Manuscript submitted for publication, 1982.

Gentner, D. R., Grudin, J., & Conway, E. Finger movements in transcription typing (Tech. Rep. 8001). La Jolla, Calif.: University of California, San Diego, Center for Human Information Processing, 1980.

Lashley, K. S. The problem of serial order in behavior. In L. A. Jeffress (Ed.), Cerebral mechanisms in behavior. New York: Wiley, 1951, 112-136.

Newell, A., & Rosenbloom, P. S. Mechanisms of skill acquisition and the law of practice. In J. R. Anderson (Ed.), Cognitive skills and their acquisition. Hillsdale, NJ: Erlbaum, 1981.

Ohala, John J. The temporal regulation of speech. In G. Font & M. Tatham (Eds.), Auditory analysis and perception of speech. London: Academic Press, 1976.

Rumelhart, D. E., July, 1982. Personal communication.

Rumelhart, D. E., & Norman, D. A. Simulating a skilled typist: A study of skilled cognitive-motor performance. Cognitive Science, 1982, 6, 1-36.

Shaffer, L. H. Timing in the motor programming of typing. Quarterly Journal of Experimental Psychology, 1978, 30, 333-345.

Sternberg, S., Monsell, S., Knoll, R. L., & Wright, C. E. The latency and duration of rapid movement sequences: Comparisons of speech and typewriting. In G. E. Stelmach (Ed.), Information processing in motor control and learning. New York: Academic Press, 1978.

Terzuolo, C. A., & Viviani, P. Determinants and characteristics of motor patterns used for typing. Neuroscience, 1980, 5, 1085-1103.

Wing, A.M., & Kristofferson, A.B. The timing of interresponse intervals. Perception & Psychophysics, 1973, 13, 455-460.

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